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A MODEL FOR PREDICTING SAND PRODUCTION IN HORIZONTAL WELLS

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ABSTRACT

Sand produced along with oil and gas causes operational, safety, environmental and severe economic challenges. The cost of installing sand control facilities which may not really be needed could also be substantial. Therefore, determining the critical flow rate for the onset of sand production is very important. There are several published studies on sanding in vertical wells, but few on horizontal wells, which have now become very prominent in the industry. The aim of this study was to develop a simple but robust model for predicting sand rates in horizontal wells. A novel geomechanical model incorporating gravity, buoyancy, drag and lift forces was developed and validated with data from 3 oil fields in the Niger Delta. The results showed that sand production could take place in horizontal wells even at low production rates but increases at high production rates in the fields of study. Critical sand rate is also affected by horizontal well length, fluid viscosity and diameter of the sand particles.

Keywords: sand production, oil production, critical rate, horizontal wells, sand control

NOMENCLATURE

A = Area of the well
d_p = Particle diameter
D = Pipe diameter
F_b = Buoyancy force
F_D = Drag force
F_g = Gravity force
F_L = Lift force
k = empirical constant

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L = Well length
Q_S = Sand rate
Q_f = Fluid rate
r = Distance from the axis of the pipe
U_m = Mean velocity of sand in the pipe
U = Fluid velocity
V_r = Magnitude of velocity of the particle relative to the fluid
ρ_f = Fluid density
ρ_p = Particle density
μ = Absolute viscosity
υ = Kinematic viscosity
R = Well radius

Subscript

b = Buoyancy
D = Drag
f = Fluid
F = Fluid
g = Gravity
L = Lift
m = Mean
p = Particle
r = Relative

INTRODUCTION

The production of solid particles together with reservoir oil and gas reduces well productivity and damage production facilities. In horizontal wells, sand particles could settle and accumulate at different positions along the borehole and lead to the reduction of cross-sectional area open to flow. This could cause partitioning of a horizontal well into segments and total loss of production.

Sand production, which can be transient, continuous or catastrophic in extent, is believed to result when there is disaggregated material around the well cavity by water and excessive drawdown and high fluid flow rate to produce the grain particles. The factors that aid sand production include geological factors, production rate, increasing water saturation and water cut. Mitigating sand production problems in horizontal wells requires sand control measures such as reducing production rate and drawdown; selective or orientation perforation; mechanical methods such as use of screens, gravel packing, frac-packing and expandable sand screens. Artificial cementation of formation sand grains by injection of chemicals such as phenol-formaldehyde, epoxy and furan can also be undertaken.

Sand-liquid flow has application in many different areas of science and engineering such as the transport of sediments in river streams, slurry pipeline transportation, drill cuttings removal and transport of proppants in hydraulically fractured wells.

LITERATURE REVIEW

To understand principles involved in solid-liquid flows, many theoretical, field and experimental studies have been undertaken over the years. An outstanding experimental investigation was reported by Thomas (1961) who noted that particles travelling below a minimum transport velocity tend to settle and accumulate at the bottom of the flow channel. Other studies have also shown that production rates affect the arch size and stability of unconsolidated sands (Tippie and Kohlhaas, 1973; Cleary et al., 1979).

To develop analytical models, it is now widely accepted that sand production can be defined using the principle of effective stress around the wellbore as proposed by Risnes et al (1982) and Morita (1994). The concept assumes that sand production can be triggered by compressive failure induced by a combination of in-situ stress and drawdown or by tensile failure induced by the near-cavity pore pressure gradient. Whether compressive failure or tensile failure prevails will depend on the in-situ stress, drawdown and flow rate in relation to the rock strength. The extreme condition of compressive failure at zero flow rate has been likened to the problem of hollow cylinder collapse (Ray et al, 1999), while tensile failure at zero near-cavity effective stress is similar to unconsolidated sand failures (Hall and Harrisberger, 1970; Risnes et al, 1982).

Van den Hoek et al (1996) presented results of theoretical and experimental studies on the prediction of sand failure around cylindrical and hemi-spherical cavities in weak sandstones under varied conditions and showed that the tendency for compressive or tensile failure depends on the well cavity size.

Changes in reservoir pressure during successive gas production and injection cycles have been known to affect the magnitude of the in-situ stresses. Addis et al (1996) provided a summary of simple, analytical models for predicting stress changes under uniaxial and plane strain conditions. The effect of cyclic loading on rock strength was also studied by Ray et al (1999), who observed that cyclic stresses within a reservoir and near wellbore area can result in gradual reduction of rock strength. Mc Lellan et al (2000) considered the risk of shear and tensile failure during production and injection cycles in gas storage wells and concluded that the risk of rock failure is smallest in the early time phase of injection operations when there is a steep, outward directed pressure gradient that effectively supports the borehole wall. The effect of capillary pressure at providing additional strength in partially saturated rocks, was described by Forsan and Schmitt (1994) who noted that capillary pressure within a rock must be included to define the effective cohesion.

In the past, it was thought that sand production cannot be associated with horizontal wells because of the small drawdown around such wells. However, it has been proved that sand production can be experienced in horizontal wells (Morita and Fuh, 1996).

Bianco and Helleck (2001) investigated the effect of water influx in poorly consolidated sandstones. Their results showed that single-phase saturated sands did not develop enough cohesive strength to support a stable arch and resulted in massive sand production. Alteration of the rock wetting phase can lead to instability and thus sand production (Han and Dusseault, 2002). A sand production model during underbalanced drilling was developed by Aadnoy and Kaarstad (2010), who concluded that cohesive strength is a critical factor.

Isehunwa and Olanrewaju (2010) adapted the geomechanical modelling approach of Vardoulakis (2006) to develop an analytical model for predicting sand production in vertical wells in the Niger Delta. This current work aimed at extending the study to the prediction of sand production in horizontal wells in the Niger Delta.

THEORETICAL FRAMEWORK

For a particle in a moving fluid, the forces acting on it would include gravity, buoyancy, drag, lift and other forces. The direction of the lift force would depend on the location of the particle compared to the walls of the flow channel. In this model it is assumed that the lift force is against the gravity force. Other assumptions made are that fluid is Newtonian, sand particles are spherical in shape and uniform in size, the particles produced from the formation settle down to the bottom, in the absence of horizontal flow component, flow is laminar and steady-state.

We can write a force balance equation for the lift, gravity, buoyancy and drag forces as:

$$F_L = F_g - F_b + F_D \tag{1}$$

where,

$$F_g = \frac{\pi d_p^3}{6} \rho_p g \tag{2}$$

$$F_b = \frac{\pi d_p^3}{6} \rho_f g \tag{3}$$

$$F_D = 3\pi\mu U d_p \tag{4}$$

For a particle of diameter d whose centre is at location r sees locally a shear rate of magnitude 16 $U_m r/D^2$, the lift force can be expressed as:

$$F_L = K\mu V_r d_p \left(\frac{U_m r}{\nu D^2}\right)^{1/2} \tag{5}$$

where,

K is a constant to be empirically determined, and

$$\nu = \frac{\mu}{\rho_f} \tag{6}$$

Substituting equation (6) into equation (5) gives:

$$F_L = K\mu^{1/2} V_r \frac{d_p}{D} U_m^{1/2} (\rho_f r)^{1/2} \tag{7}$$

In a Poisseuille flow through a pipe of diameter, D, if we assume the sand particle is initially stationary at the bottom of the pipe, and the axial location r of the sand particle is given by equation (8),

$$r = \frac{(D - d_p)}{2} \tag{8}$$

The relative velocity of the particle can be expressed as:

$$V_r = 2U_m \left(1 - \frac{(D - d_p)^2}{D^2}\right) \tag{9}$$

Substituting equation (9) into equation (7) gives:

$$F_L = 2K\mu^{1/2} U_m^{3/2} B \frac{d_p}{D} \left(\rho_f \left(\tfrac{D-dp}{2}\right)\right)^{1/2} \tag{10}$$

where,

$$B = \left(1 - \frac{(D - d_p)^2}{D^2}\right) \tag{11}$$

Therefore substituting all the relevant terms into equation (1), we have:

$$2K\mu^{1/2} U_m^{3/2} B \frac{d_p}{D} (\rho_f r)^{1/2} = \frac{\pi d_p^3 g}{6} (\rho_p - \rho_f) + 3\mu\pi U d_p \tag{12}$$

where, U_m is the critical velocity of the particle in horizontal wells.

$$U_m = \frac{Q_s}{A} \tag{13}$$

$$U = \frac{Q_F}{A} \tag{14}$$

For a horizontal well of length L, we define the effective area A as:

$$A = 2\pi RL \tag{15}$$

Therefore, the sanding rate can be expressed as:

$$Q_S = 2\pi RL\left(C\left(\frac{\pi d_p^3 g}{6}(\rho_p - \rho_f) + 1.5\mu \frac{Q_F}{RL} d_p\right)\right)^{2/3} \tag{16}$$

where,

$$C = 1 \Big/ 2K\mu^{1/2} B \frac{d_p}{D}\left(\rho_f\left(\frac{D-dp}{2}\right)\right)^{1/2} \tag{17}$$

For easier practical application, we modify equations (16) and (17) and express the critical rate for sand production as:

$$Q_{Sc} = 2\pi RLk\left(C^*\left(\frac{\pi d_p^3 g}{6}(\rho_p - \rho_f) + 1.5\mu \frac{Q_F}{RL} d_p\right)\right)^{2/3} \tag{18}$$

where,

$$k = \left(\left(\frac{1}{K}\right)\right)^{2/3} \tag{19}$$

$$C^* = 1 \Big/ 2\mu^{1/2} B \frac{d_p}{D}\left(\rho_f\left(\frac{D-dp}{2}\right)\right)^{1/2} \tag{20}$$

APPLICATION, RESULTS AND DISCUSSION

Equation (18) represents a simple expression that can be used to predict sand production in horizontal wells. It incorporates the effect of gravity, buoyancy and drag forces. The equation shows that sand production is expected to increase with hole size, horizontal length, particle size, density contrast between sand and fluid, fluid viscosity and production rate.

Data from 3 adjacent oil fields located onshore western Niger Delta, about 200 km south east of Lagos were used. The reservoirs are mainly unconsolidated shoreface sands of Tertiary age. Average porosity and permeability is about 0.28 and 1200 mD respectively. The fields have produced for over 15 years and current total oil production is about 50,000 b/d. Oil gravity varies between 21 and 32 API, while viscosity varies between 1.0 and 5.0 cp. Other input data are as listed in Table 1 while the field-derived empirical constants are given in Table 2. Figures 1-4 show the sand production trends with oil rates. It is clear that sand production commenced in all the fields even at rates below 200 bbl/day and increased at high production rates in field A and B. The early sanding could be due to the sanding mechanism in the Niger Delta (Isehunwa and Farotade, 2009). Figure 1 shows that without calibration, application of equation (16) to field A, will overpredict the sand rates. In all the fields, sanding increased with increasing oil rates, while the effect of horizontal length is more pronounced at high than low offtake rates.

Table 1. Inputs parameters

Parameters	Range
Oil API	21.4 - 31.7
Pipe Diameter (ins)	9.0
Average viscosity, cp	2 cp
Particle diameter (ins)	0.0118
Well length, ft	1000- 3000

Table 2. Field derived empirical constants

FIELD	Empirical Constant, k
A	$3.0 * 10^{-7}$
B	$4.0 * 10^{-6}$
C	$1.5 * 10^{-7}$

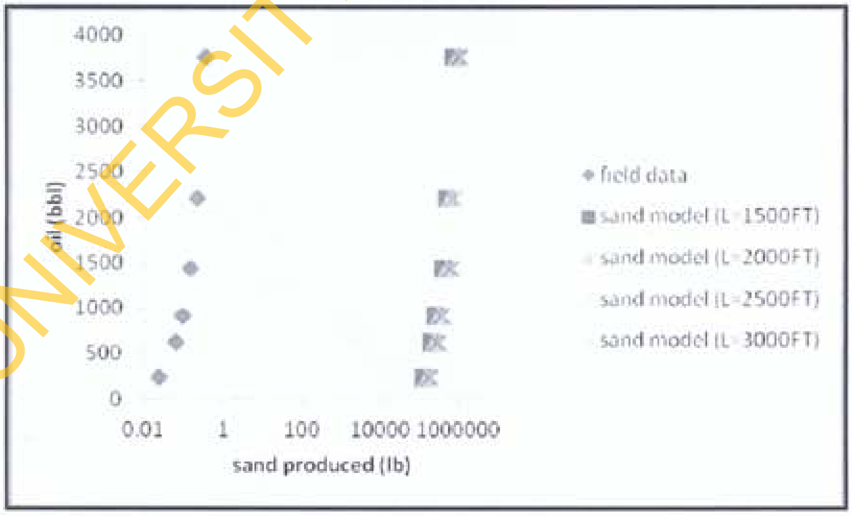

Figure 1. Sand Production Prediction in Field A without Calibration.

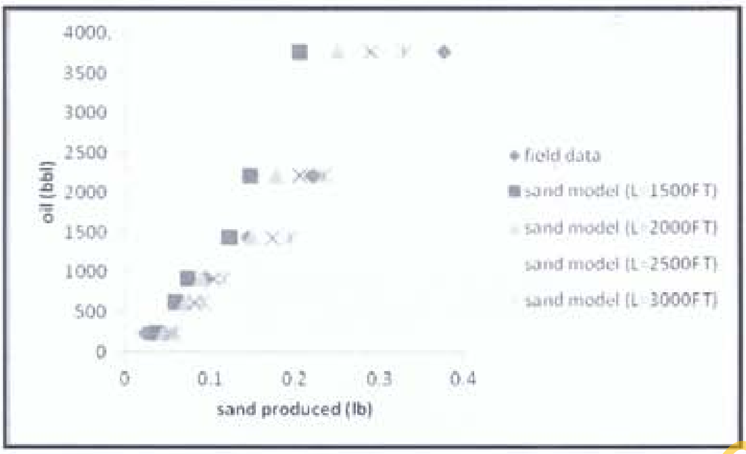

Figure 2. Sand Production Prediction in Field A (with Calibration).

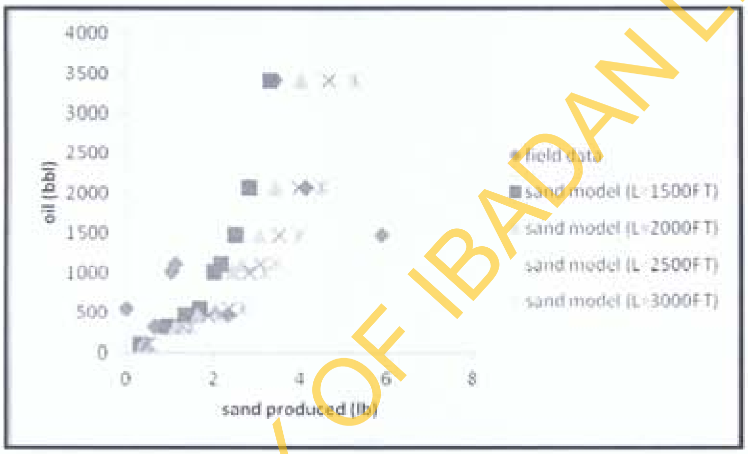

Figure 3. Sand Production Prediction in Field B (with Calibration).

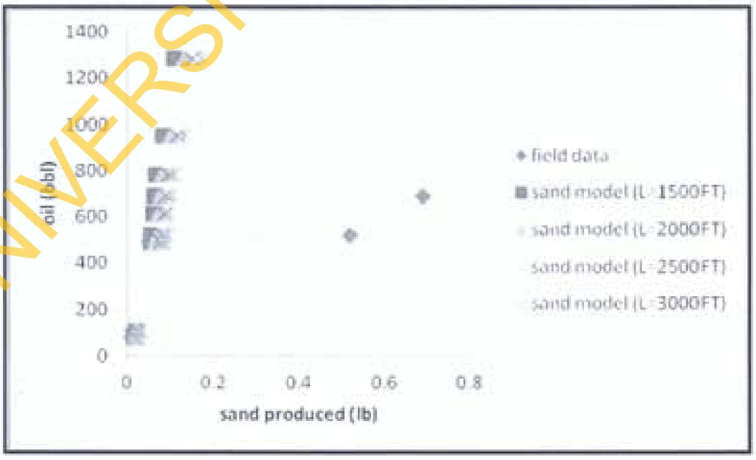

Figure 4. Sand Production Prediction in Field C (with Calibration).

CONCLUSION

A simple geomechanical model has been developed for predicting sand production in horizontal wells. The model shows that sand production is affected by hole size, horizontal length, particle size, density contrast between sand and fluid, fluid viscosity and production rate. Application to three oil fields in the Niger Delta demonstrated that sand production can be experienced even at low rates in some oil fields and horizontal length contributes to sanding in addition to high offtake rates.

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